

PRELIMINARY REPORT ON
EVAPORATION FROM SNOWDRIFTS
UNDER OASIS CONDITIONS

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December 1, 1973

A
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WATER RESOURCES RESEARCH INSTITUTE

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ABSTRACT

Considerable research has shown that it is possible to modify snow accumulation patterns by utilizing artificial wind barriers, such as snow fences. However, economical utilization of the snowdrifts requires that the resultant increase in water supply be obtained at a reasonable cost which assumes an ability to estimate the increase. To determine the quantity of increased water supply, it is necessary to know the amount of water lost from the drift through evaporation.

A study to measure evaporation was conducted on Pole Mountain in southeastern Wyoming, wherein two snowdrifts were formed on top of butyl rubber mats behind two separate snow fences, each 8 feet high (2.4 m) x 100 feet (30 m) long. The water equivalents of the drifts were determined, and the quantity of runoff from the melting of the drifts was measured. Since there could be no infiltration, the

difference between the water equivalency of the drift and the runoff was a measure of the evaporation, which during the one-month ablation period, was approximately 20-30 percent of the volume of the drift at the start of ablation.

During the melt season the snowdrifts are "oases" of snow, in that they are surrounded by bare ground. Because of this fact, and the extreme wind packing of the snow, existing models to compute evaporation are not adequate.

KEY WORDS: Evaporation/ Sublimation/ Snow Drifts/ Water Supply

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This report is presented as a preliminary report because the research is continuing with some additions during the winter of 1973-1974 under a new agreement.

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INTRODUCTION

Tabler (1973) has shown that a large percentage of the precipitation that falls in the form of snow in windy areas such as southeastern Wyoming, sublimates when it is transported by wind and is therefore lost to beneficial use by man at that site. He has further shown that snow fences, if properly designed, are a viable watershed management tool, and can be used to decrease the loss by sublimation, and consequently, might increase the water supply available for beneficial purposes.

Before the economic feasibility of building fences for the storage of water in snowdrifts can be established, it is necessary to determine the loss of water from the drifts themselves. Thus, the purpose of this study was to determine the evaporation from two snowdrifts under controlled conditions.

The study site is on Pole Mountain in the Medicine Bow National Forest, 17 miles (27 km) east of Laramie, Wyoming at an elevation of 8,100 feet (2,470 meters). Annual (October - May) snowfall amounts at this site vary from about 6 to 16 inches (160 - 400 mm) water equivalent, with snowpack typically beginning to accumulate in early November, reaching a peak in April and disappearing by June. The area is comprised of grasslands with scattered rock outcrops, and is subject to frequent winds of relatively high speeds and prolonged duration. The terrain slopes gently down to the east (downwind), and there is an effective barrier to blowing snow about 1,100 feet (335 meters) west (upwind) of the fence locations. The soil consists of decomposed granite which is very

porous; therefore, overland flow occurs rarely and infiltrates within very short distances.

Two separate snow fences were constructed; each was 100 feet (30 m) long and 8 feet (2.4 m) high with a 6 inch (.2 m) gap between the bottom of the fence and the ground. One of the fences was made of standard vertical-lath, highway-type fencing with an approximate density of 50 percent. The other was a plastic-coated fiber glass fencing material with a density of about 55 percent. Each type of fence performed satisfactorily in forming the drift. A 1/32 in. (.08 cm) butyl rubber mat was laid in the lee of each of the fences with a berm all around to prevent water from running off of or onto the mat. Wind currents did cause the drift to spill over the edge of the mat, which necessitated digging a trench through the drift at the mat boundary. This precluded melt water from following an ice layer and running off the mat, and thus not being recorded as runoff.

The area was selected for the study because the U. S. Forest Service, Rocky Mountain Forest and Range Experiment Station, has an ongoing study of the utilization of snow fences for snow storage on watersheds (Tabler, 1971) in the vicinity. In addition, the persistent winds cause the relocation of snowfall, so that in unforested areas snow accumulation occurs only in topographic depressions, the lee of scattered rocks and trees, and behind snow fences. The remaining area is without snow cover most of the winter, especially during the drift ablation season. Thus, a drift behind a snow fence is isolated from nearby snowpack and is, in essence, an oasis.

When the snow melts, the melt water either contributes to the water supply as runoff in the streams or infiltration to the groundwater, or is lost to the atmosphere through evaporation. In addition, there may also be some loss due to sublimation. For purposes of discussion, evaporation and sublimation will be lumped together as evapo-sublimation.

In order to determine the evapo-sublimation from a snowdrift, it is necessary to measure all the components of the water budget equation:

$$M = R + E + I, \quad (1)$$

where M = Snow melt ablation of the drift

R = Runoff

E = Evapo-sublimation

I = Infiltration.

Infiltration is almost as difficult to measure directly as evaporation; therefore, in this study infiltration, I, was made equal to zero by the placement of a waterproof butyl rubber mat under the drift. The water budget equation then became

$$M = R + E. \quad (2)$$

The rubber mat was shaped such that all water on it would drain to one outlet point, where two weirs were placed (one below the other) to measure all runoff, R, from the drifts. Two weirs were used as a precautionary measure in case one of the weirs or its recorder failed. One was a 90° v-notch weir and the other a 45° v-notch weir; both were heated so the water would not freeze. The larger weir (90°) was used in case preliminary calculations of

discharge rate were low and the capacity of the 45° weir was exceeded. The weirs were calibrated in the hydraulics laboratory at the University of Wyoming. The heads on the weirs were recorded, and to insure a continuous record of discharge, two recorders were used (one on each weir) on the assumption that both recorders would not fail at the same time.

The change in the water equivalent of the drift, ΔQ , (Q initial minus Q final), is the ablation due to snow melt minus additions to the drift during the time interval, or

$$-\Delta Q = M - P - D, \quad (3)$$

where P = Precipitation on the drift

D = Accumulation on the drift from blowing snow.

Obviously $-\Delta Q$ will equal M for periods when there is no input to the drift. During the spring ablation the blowing of snow is minimal, so during this period $-\Delta Q$ will equal $M - P$. Substituting equation (2) into equation (3) gives:

$$-\Delta Q = R + E - P - D, \text{ or} \quad (4)$$

$$E = -\Delta Q + P + D = R. \quad (5)$$

The change in water equivalent of the drift, ΔQ , was determined by measuring the volume and density of the drift at weekly intervals. The precipitation, P , was measured by several gages installed at the site. For this study it was not feasible to measure the accumulation to the drift from the capture of blowing snow, D . Therefore M , and thus also the evapo-sublimation were determined only for periods when D was zero.

The measurement of the water equivalent in the drift and the weekly ablation of water equivalent from the drift had to be as precise as possible in order that the evapo-sublimation can be determined with the desired degree of accuracy. To accomplish this precision, the drift volume was determined by surveying, and the drift density was determined using the Federal Mt. Rose snow sampler to take samples at 10-foot (3.1 m) intervals along a transect down the center line of the drift. For purposes of comparison other drifts nearby were intensively sampled at various times during the year. The average densities of all of the drifts did not vary more than 2 percent, which is within the accuracy of the sampler.

Tables 1 and 2 show the computations made to determine evapo-sublimation loss from the two drifts during the melt season from April 26, 1973 through May 30, 1973. April 26 was the date of maximum snow accumulation in the drifts, and the last remnant of Drift No. 1 disappeared on May 30, while Drift No. 2 disappeared one day later.

The first week of the melt season (April 26 - May 3) was preceded by a large storm, and was cold and snowy with strong winds from the north (parallel with the fences). The computed evapo-sublimation rate was high during this period, so cross-sections of the drifts were inspected to determine if some of the unconsolidated snow was eroded during that week. The cross-sections on both drifts indicated that the increase in snow volume between April 12 and 26 occurred at the tail of the drifts, with some consolidation occurring in the main body of the drift. Evidently the tail of the

Table 1

WATER BUDGET OF SNOW DRIFT NO. 1

Pole Mountain, Wyoming - Elevation 8,100 feet

April 26 - May 31, 1973

Date	Drift Vol.	Drift Density	Drift WE	Runoff During Period	Precip. During Period	Drift Surface Area	Apparent Evapo-Sub.	
	ft ³	%	ft ³	ft ³	ft ³	ft ²	ft ³	in.
	(m ³)		(m ³)	(m ³)	(m ³)	(m ²)	(m ³)	(mm).
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Apr. 26	67,537 (1,913)	46	31,067 (880)			13,485 (1,253)		
Δ or Σ			-3,927 (111)	129 (4)	776 (22)	13,485 (1,253)	4,574 (130)	4.07 (103)
May 3	58,999 (1,671)	46	27,140 (769)			13,485 (1,253)		
Δ or Σ			-5,304 (150)	4,837 (137)	472 (13)	13,477 (1,252)	939 (127)	0.84 (21)
May 11	38,309 (1,085)	57	21,836 (618)			13,470 (1,251)		
Δ or Σ			-10,068 (285)	5,796 (164)	0 (0)	11,310 (1,051)	4,272 (121)	4.53 (115)
May 17	18,981 (538)	62	11,768 (333)			9,150 (850)		
Δ or Σ			-8,695 (246)	6,895 (195)	146 (4)	6,705 (623)	1,946 (55)	3.48 (88)
May 22	5,392 (153)	57	3,073 (87)			4,260 (396)		
Δ or Σ			-2,049 (58)	2,159 (61)	169 (5)	3,390 (315)	59 (2)	0.21 (5)
May 25	1,626 (46)	63	1,024 (29)			2,520 (234)		
Δ or Σ			-1,024 (29)	869 (125)	371 (10)	1,260 (117)	526 (15)	5.01 (127)
May 30	0	-	0			0		
Total-Apr. 26-May 30			-31,067 (880)	20,685 (586)	1,934 (55)		12,316 (350)	18.14 (461)
Total-May 3-May 30			-27,140 (769)	20,556 (582)	1,158 (33)		7,742 (220)	14.07 (358)

Table 2

WATER BUDGET OF SNOW DRIFT NO. 2

Pole Mountain, Wyoming - Elevation 8,100 feet

April 26 - May 31, 1973

Date	Drift Vol.	Drift Density	Drift WE	Runoff During Period	Precip. During Period	Drift Surface Area	Apparent Evapo-Sub.	
	ft ³	%	ft ³	ft ³	ft ³	ft ²	ft ³	in.
	(m ³)		(m ³)	(m ³)	(m ³)	(m ²)	(m ³)	(mm.)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Apr. 26	56,032 (1,587)	46	25,775 (730)			13,370 (1,242)		
Δ or Σ			-3,128 (-89)	602 (17)	791 (22)	13,070 (1,214)	3,317 (94)	3.05 (78)
May 3	49,233 (1,394)	46	22,647 (641)			12,770 (1,186)		
Δ or Σ			-3,015 (-85)	3,268 (93)	482 (14)	11,335 (1,053)	229 (7)	0.24 (6)
May 10	35,704 (1,011)	55	19,632 (556)			9,900 (920)		
Δ or Σ			-7,880 (-223)	6,198 (176)	0 (0)	8,755 (813)	1,682 (48)	2.30 (58)
May 17	19,586 (555)	60	11,752 (333)			7,610 (707)		
Δ or Σ			-7,363 (-209)	5,187 (147)	57 (2)	6,465 (610)	2,233 (63)	4.14 (105)
May 21	7,568 (214)	58	4,389 (124)			5,320 (494)		
Δ or Σ			-1,082 (-31)	908 (126)	92 (3)	5,105 (474)	266 (8)	0.63 (16)
May 22	5,702 (161)	58	3,307 (93)			4,890 (454)		
Δ or Σ			-2,061 (-58)	2,207 (62)	172 (5)	3,845 (357)	26 (1)	0.08 (2)
May 25	2,042 (58)	61	1,246 (35)			2,800 (260)		
Δ or Σ			-1,246 (-35)	1,246 (35)	379 (11)	1,400 (130)	379 (11)	3.25 (83)
May 31	0	-	0			0		
Total-Apr. 26-May 31			-25,775 (730)	19,616 (556)	1,973 (56)		8,132 (232)	13.69 (348)
Total-May 3-May 31			-22,647 (641)	19,014 (539)	1,182 (33)		4,815 (138)	10.64 (270)

drift was not packed as firmly as the main body and with the high winds out of the North during the week of April 26 to May 3, some of the snow in the drift was relocated. It is probable that the relocated snow also evapo-sublimated, but because of some uncertainty, the computations of evapo-sublimation were made with and without the data from this weekly period.

The study shows that for Drift No. 1, the evapo-sublimation loss during May was $7,742 \text{ ft}^3$ (220 m^3), or 20 percent of the volume of water equivalent in storage at the beginning of the period. If the figures for the first week (the last week of April) are included the loss was 40 percent. For Drift No. 2 the evapo-sublimation loss for May was $4,815 \text{ ft}^3$ (138 m^3), or 21 percent of the initial drift water equivalent volume. For the entire period April 26 - May 31, the loss was 32 percent of the initial volume.

Although Drift No. 2 had a smaller starting volume than Drift No. 1, by May 17 the volumes were equal because Drift No. 1 had consistently experienced more evapo-sublimation loss than Drift No. 2. Drift No. 2, however, was more isolated from other nearby drifts and therefore, should have been subject to more of an "oasis effect."

Total ablation, M, (evapo-sublimation plus runoff) rather than just evapo-sublimation, per average surface area of the drifts during the weekly periods is shown in Table 3 below:

Table 3

Comparison of Total Ablation per Drift Surface Area

Time Period (1973)	Total Ablation (M = E + R)		Mean Surface Area of Drift (A)		M/A		Ratio M/A $\frac{\text{Drift 1}}{\text{Drift 2}}$
	ft ³	m ³	ft ²	m ²	ft.	m.	
	Drift No. 1						
4/26-5/3	4,703	133	13,485	1,253	.35	.11	
5/3-5/11	5,776	164	13,477	1,252	.43	.13	
5/11-5/17	10,068	285	11,310	1,051	.89	.27	
5/17-5/22	8,841	250	6,705	623	1.32	.40	
5/22-5/25	2,218	63	3,390	315	.65	.20	
5/25-5/30	1,395	40	1,260	117	1.11	.34	
Drift No. 2							
4/26-5/3	3,919	111	13,070	1,214	.30	.09	1.17
5/3-5/10	3,497	99	11,335	1,053	.31	.09	1.39
5/10-5/17	7,880	223	8,755	813	.90	.27	.99
5/17-5/22	8,594	243	6,250	581	1.38	.42	.96
5/22-5/25	2,233	63	3,845	357	.58	.18	1.12
5/25-5/31	1,625	46	1,400	130	1.16	.35	.96

From this table it can be seen that the two drifts are ablating quite uniformly. The two time periods of greatest disparity are the first and second. The reason for the variance during these time periods is that Drift No. 1 covered the entire rubber mat (13,485 ft², 1,253 m²) while Drift No. 2 had a maximum surface area of 13,370 ft² (1,242 m²)

on a mat of $13,775 \text{ ft}^2$ ($1,280 \text{ m}^2$). Through May 11, Drift No. 1 continued to cover most of its mat while the mat under Drift No. 2 was being exposed more and more. The depth of the tail under Drift No. 2 was less than that of Drift No. 1 and the ablation reduced the surface area without producing as much total ablation.

The reason why Drift No. 1 had more evapo-sublimation than Drift No. 2 must be due to some subtle differences in the aspects of the two drifts. These factors will be explored in more detail during the 1973-74 season.

It was hoped that by taking measurements of the drift volume throughout the winter an estimate of winter evapo-sublimation loss could be obtained. There was so much snow during the winter, however, that there was no complete period between measurements when drifting, D , was negligible; therefore no meaningful estimates could be made.

The hydrograph of runoff from one of the drifts is shown in Figure 1. The diurnal fluctuations very closely followed the temperature and radiation sequence, with peak flows occurring daily about 2 or 3 p.m. and minimum flows about 6 or 7 a.m., while the increase in runoff to May 18 corresponded to ablation of about 65 percent of the initial volume, or between 50 and 60 percent of the volumes in the drifts as of May 3. The sharp spikes on the hydrograph are the result of rainfall on the mat.

The evapo-sublimation amounts were converted to inches (or mm) by dividing by the average drift surface area. This is not exactly correct because the major ablation takes place at the edges of the drift. Yet, in order to compare evaporation rates as observed with those computed by previously derived models, it is necessary to have the rate expressed in depth units.

Because of the oasis effect it was hypothesized that existing models of evaporation are not adequate. Models used for testing were those of Light (1941), Kuz'min (1953), Corps of Engineers (1956), and Sabo (1956). Climatological data for application to the models were collected at the site. Incoming and reflected short wave radiation were measured with Kipp and Zonen solarimeters, with backup measurement of incoming radiation provided by a Belfort pyrheliograph. Net total radiation was observed with a Fritschen net radiometer. Air temperature and humidity data were obtained from a hygrothermograph placed in a cotton region shelter adjacent to the drifts. Wind speed and direction were measured by an MRI recording gage. Due to malfunction of some of the instruments, some of the daily values had to be estimated from weekly totals; however an attempt was made to apply the models on a daily basis and to compare the computed evaporation with the observed evapo-sublimation on weekly and monthly totals. All of the models significantly underestimated the evaporation as can be seen in the following table.

Table 4

Comparison of Observed and Computed Evapo-Sublimation

May 3 - May 31, 1973

Observed Evapo-Sublimation				Evaporation as computed by:							
Drift No. 1		Drift No. 2		Light		Kuz'min		Corps		Sabo	
in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.
14.07	358	138	270	1	25	0.1	3	2	51	0.3	7

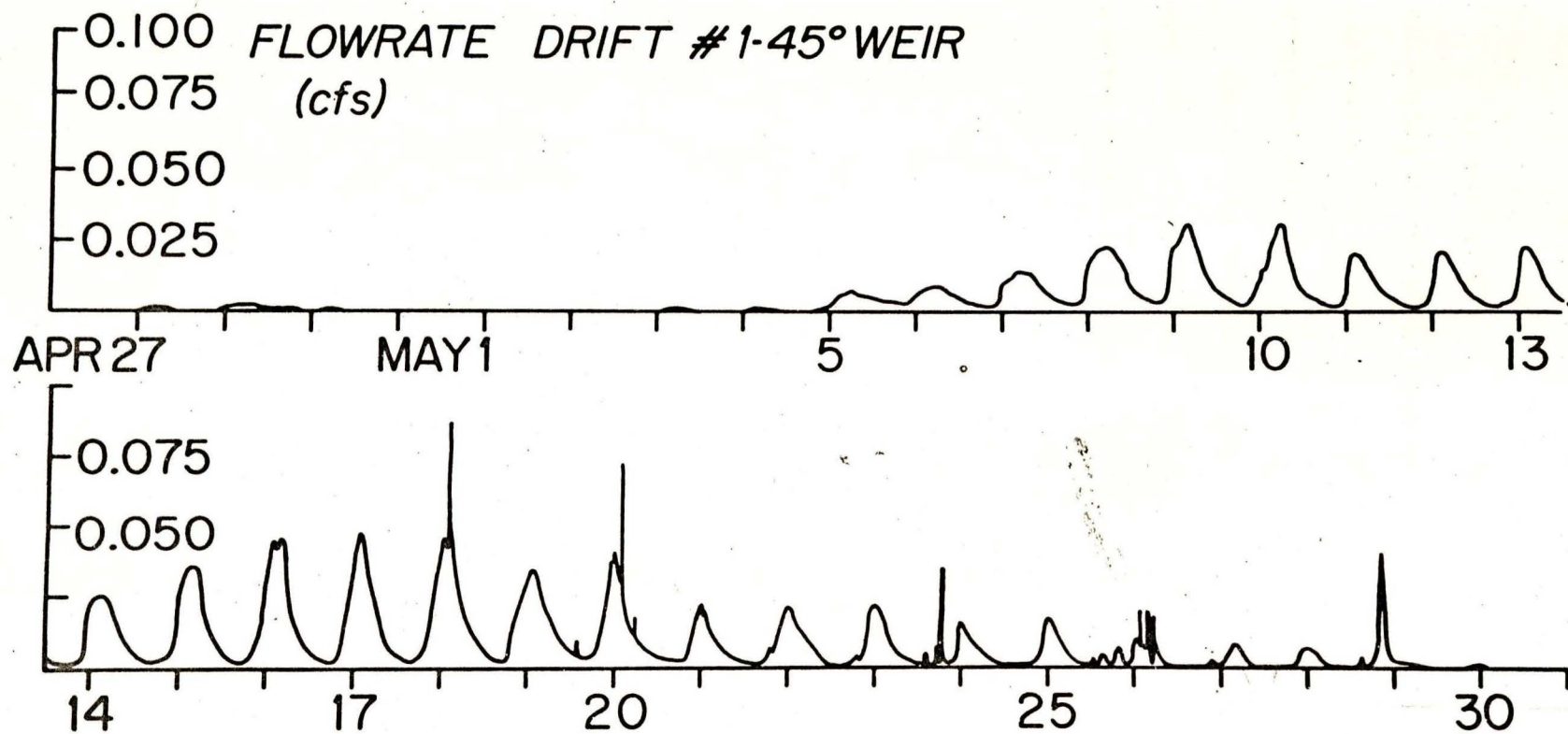


Figure 1. Hydrograph of Runoff from Drift No. 1 as Measured by 45° weir - Pole Mountain Area

CONCLUSIONS

It is concluded from the first year of operation of this study that during the ablation period evapo-sublimation from snowdrifts under oasis conditions approximates 20 to 30 percent of the water equivalent volume of the drift at the start of ablation.

Because the snowdrifts are under oasis conditions and because they are wind packed and therefore more dense than usual snow pack, existing models to compute evaporation from snow are not adequate.

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